HAWAII DEEP WATER CABLE PROGRAM

PHASE II

LABORATORY TEST PROTOCOL

ates of America

nent of Energy

HAWAII DEEP WATER CABLE PROGRAM

PHASE II

LABORATORY TEST PROTOCOL

Prepared by

Pirelli Cable Corporation
and
Societa Cavi Pirelli

Prepared for

The Ralph M. Parsons Company,
Hawaiian Electric Co., Inc.
and the
U.S. Department of Energy

MAY 1986

HAWAII DEEP WATER CABLE (HDWC) PROGRAM

LABORATORY TEST PROTOCOL

TABLE OF CONTENTS

1.0 OBJECTIVE

The objective of the laboratory test program is to demonstrate that the selected cable and joints are capable of withstanding the expected mechanical stresses and environmental conditions to be encountered during deployment, retrieval and in operation while retaining the electrical characteristics necessary for a service life exceeding 30 years. In addition, the objective is to obtain data to optimize the final cable system design.

Routine and Type (Qualification) Tests, based on Electra No. 68 and No. 72, will be performed by the manufacturer on full cable lengths or on sample cable lengths, as applicable, from the same production lot as will be used for the laboratory test program. A detailed description of the qualification tests is included in Appendix A for reference purposes.

2.0 LABORATORY MECHANICAL AND ELECTRICAL TESTS

This Laboratory Test Protocol has been developed to demonstrate technical feasibility of the cable system and incorporates (1) mechanical tests on the cable system to simulate stresses likely to be experienced during installation, recovery and under operating conditions including tidal currents and bottom currents over at least a thirty-year life and (2) electrical tests to demonstrate a life expectancy of greater than thirty years under the anticipated mechanical stresses.

The test program described in this document is separated into two parts:

- Individual tests to verify the performance of the cables and joints under single worst conditions.

- Sequence tests which cumulate the principal events foreseen in the deployment and long term operation of the cable and joints.

The two parts of the test program are respectively preceded by a chart which permits an overview of the test program and the significant details thereof.

In the laboratory test program, reference is made to Electra No. 68 and Electra No. 72 for test procedures. Electra No. 68 refers to "Recommendations for Mechanical Tests on Submarine Cables" and Electra No. 72 refers to "Recommendations for Tests of Power Transmission DC Cables for a Rated Voltage Up to 600 kV" both developed under the auspices of CIGRE Study Committee 21.

The tests procedures and related equipment are specific in the case of the qualification tests which are standard tests referred to in Electra No. 68 and No. 72. Such is not always the case for the non-standard laboratory tests where many of the details can only be finalized in the course of setting up the test and, in isolated cases, while the tests are in progress.

The number of repeat tests specified in the laboratory test program is predicated on the following considerations:

- Scatter of test data normally experienced in the performance of a specific test.

- Relative position of the statistical distribution of the test data compared to the level of performance that is required.

In the specific case of self contained oil filled cable, which is generally true for oil impregnated laminar dielectric cable, the manufacturing process provides extreme uniformity of the insulation which will not be impaired by thermal cycling. Hence, insofar as electrical tests are concerned, a single test is sufficient. In the case of mechanical tests, including those tests that relate to fatigue of the lead sheath, the number of repeat tests specified relate to the criteria mentioned above and are further influenced by the fact that the test conditions have been accelerated compared to the expected stresses during deployment, retrieval and repair operations.

LABORATORY INDIVIDUAL TESTS

SUMMARY OF LABORATORY INDIVIDUAL TESTS

Test	Description	Electrical	Joint	Tension	Length
LI-1	Baseline Electrical Test	.PF .DC Withstand .Impulse Withstand & Breakdown	No Joint		40 m
LI-2	Bending & Electrical Test	.Load Cycle & Polarity Reversal .Impulse Withstand & Breakdown	Repair Joint	85T	120 m
LI-3	High Stress Tensile Test	No Electrical	Factory Joint	148T	50 m
LI-4	Repeated Flexure Test	No Electrical	No Joint	To be determined	120 m
LI-5	Static Flexural Rigidity	No Electrical	No Joint		included in LI-6
LI-6	Dynamic Flexural Rigidity and Dampening Coefficient	No Electrical	No Joint		80 m
LI-7	Cable Oscillation Test Under Tidal Action	No Electrical	No Joint		80 m
LI-8	Lead Sheath Fatigue Test	No Electrical	No Joint		60 m
LI-9	Friction Force Test	No Electrical	No Joint	2 T	30 m
LI-10	Crushing Test	No Electrical	No Joint	85 T	60 m
LI-11	Sleeving Test	No Electrical	No Joint	85 T	80 m

3.0 LABORATORY INDIVIDUAL TESTS

3.1 BASELINE ELECTRICAL TEST LI-1

3.1.1 Purpose

The purpose of this test is to provide baseline electrical data on a length of as manufactured cable and to allow the quantification of the degradation of cable samples subjected to the mechanical tests in LI-2 and the Laboratory Sequence Tests (LS-1 through LS-4).

3.1.2 Test Procedure

Power Factor

The power factor of the cable sample shall be measured in accordance with Clause 8 of Cigre No. 72 at ambient temperature with care taken to minimize the influence of the terminations. Should the measurements be taken at a temperature below 20°C the correction procedure stipulated in Clause 8 shall be applied.

The maximum power factor at the voltage stresses of 10 kV/mm and 20 kV/mm shall be 40×10^{-4} and 52×10^{-4} respectively. The maximum power factor difference between 10 and 20 kV/mm (ionization factor) shall be 14×10^{-4}. The oil pressure on the cable at the highest position shall be adjusted to a value of 700 kPa (7 bars). This oil pressure is sufficiently high to closely approach the electrical properties of the cable at its operating pressure of 25 to 30 bars while facilitating the performance of the test.

D.C. High Voltage Test

The cable sample shall be subjected to a negative direct current voltage of 600 kV (2 Uo) between conductor and sheath for 15 minutes at room temperature in accordance with Clause 7 of Cigre No. 72. The oil pressure at the highest position shall be adjusted to a value of 700 kPa (7 bars).

Lightning Impulse Test

The test shall be conducted in accordance with Clause 11, subparagraph 11.2, of Electra No. 72 and the referenced IEC Publication No. 230. The oil pressure at the highest position shall be adjusted to a value of 700 kPa (7 bars). The conductor shall be current loaded to a temperature of 90°C (maximum rated temperature plus 5°C).

After demonstration of the impulse withstand voltage of 775 kV, the impulse voltage shall be increased in steps of 25 kV until breakdown occurs.

For engineering information the cable shall be dissected in the region of the breakdown area to determine the breakdown path, cause of failure. A detailed examination of all components of the insulation structure of the cable shall be conducted and reported. Specifically, the tape shield and insulation structure shall be examined for uniformity of gaps, creases, torn tapes and registrations.

3.1.3 Test and Measuring Equipment

a) Power factor bridge (Table 1)
b) D.C. generator (Table 1)
c) Impulse generator (Table 1)
d) Laboratory terminations (2) (Table 1)
e) Current heating transformers (Table 1)
f) Low and High Pressure Oil Reservoirs (Table 1)
g) Temperature monitoring and recording equipment (Table 1)
h) Special cable oil (1000 liters)
i) Oil processing equipment (Table 1)

3.1.4 Data to be Reported

a) Cable power factor and ionization values
b) Ambient temperature
c) DC voltage test results
d) Impulse breakdown value
e) Results of dissection and analysis of failure
f) Cable pressure
g) Temperature of conductor and sheath

3.1.5 Number of Tests

One

3.1.6 Length of Cable Sample

40 m

3.2 BENDING AND ELECTRICAL TEST LI-2

3.2.1 Purpose

The purpose of this test is to demonstrate that the electrical characteristics of the cable and repair splice will not be impaired by the forces that may occur during at-sea deployment and recovery operations. In addition, the test will provide data to allow a comparison between the results of this test and a similar test conducted under the qualification testing program.

3.2.2 Test Procedure

Bending Test

The mechanical set-up for performing the bending test shall be in accordance with Figure 1 of Electra No. 68. Alternatively, the bending of the cable shall be accomplished as shown in Figure 1:

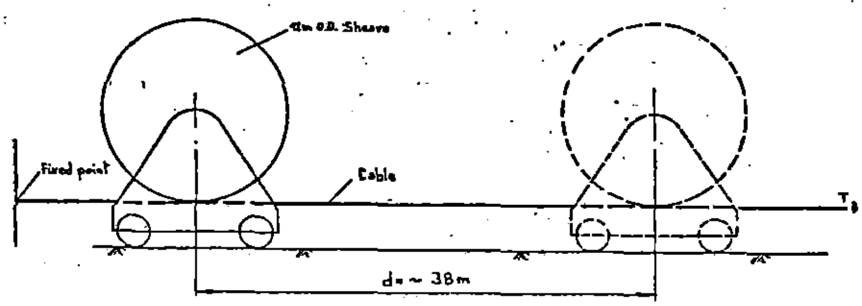


Fig. 1 Bending Test
T = Applied Cable Tension
d = Sheave Horizontal Displacement

The cable ends shall be secured with mechanical heads that are designed to join all metal components of the cable in such a manner as to provide the same distribution of tensile load as will be experienced during cable deployment.

See paragraph 3.2 of Electra No. 68 for details of the bending test. The oil pressure at the highest position shall be adjusted to a value of 700 kPa (7 bars). The test shall be performed on a length of cable containing a repair splice. The cable shall be wound on a drum having a diameter of 12 m which will be the diameter of the overboarding sheave to be used on the cable laying vessel. During the bending tests, the cable shall be subjected to a tension of 85 tons which is calculated using the following formula:

$$T = 1.15\ (1.3\ Wh + 6.8) \qquad \text{tons}$$

where: W = weight of cable in water
= 0.027 ton/m (27 kg/m)

h = maximum anticipated depth of deployment
= 1915 m

Note: The above formula differs from that in Electra No. 68 due to the inclusion of a safety factor of 15 percent and a higher bottom tension due to the greater difficulty in controlling bottom tension at the greater deployment depth of 1915m. The 85 tons tension calculated above corresponds to a depth of 2307 m calculated using the formula in Electra No. 68.

Although the maximum depth at which a repair splice can be made will be in the order of 600 m, it is considered desirable to demonstrate that the repair joint can withstand the same tensile forces as the cable and factory joint.

Load Cycle and Polarity Reversal Test

After the bending test, the cable sample containing a repair joint shall be subjected to the load cycle and polarity reversal test.

This test, comprising 30 loading cycles, shall be performed in accordance with clause 10 of Electra No. 72. A loading cycle shall consist of 8 hours heating, at the end of which the conductor temperature shall be not less than 90°C (maximum rated temperature plus 5°C) and the temperature across the insulation shall be 11 K (maximum design value for this cable design and application). The 30 loading cycles are divided into 3 tests of 10 cycles each.

The first 10 loading cycles shall be carried out with a positive dc voltage of 600 kV (2 Uo) applied between the conductor and sheath.

The next 10 loading cycles shall be carried out with a negative dc voltage of 600 kV (2 Uo) applied between the conductor and sheath.

The third 10 loading cycles shall be carried out with a dc voltage of 450 kV (1.5 Uo) applied between the conductor and sheath. Starting with positive voltage the voltage polarity shall be reversed every 4 hours and one reversal shall coincide with the cessation of loading current in every loading cycle. The recommended time duration for a polarity reversal is maximum of 2 minutes however the time duration may be extended to 10 minutes maximum if the insulation time constant is long.

Lightning Impulse Test

This test shall be conducted in accordance with Clause 11, subparagraph 11.2, of Electra No. 72 and the referenced IEC Publication No. 230. The oil pressure at the highest position shall be adjusted to a value of 700 kPa (7 bars). The conductor shall be current loaded to a temperature of 90°C (maximum rated temperature plus 5°C).

After establishing of the impulse withstand voltage of 775 kV, the impulse voltage shall be increased in steps of 25 kV until breakdown occurs.

For engineering information, the cable shall be dissected in the region of the breakdown area to determine the cause of failure. This examination shall include determination of the failure path and condition of the tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes and registrations, on both sides of the failure. In addition, should the cable failure not occur within the repair splice, the splice shall be dissected and a detailed examination of all components shall be conducted and recorded.

3.2.3 Test and Measuring Equipment

Mechanical

a) 12 m sheave with trolley
b) Tensile test facility (100 tons)
c) Cable mechanical end heads (2)
d) Tensile recorder
e) Load cell (100 tons)
f) Low and high pressure oil reservoirs (Table 1)
g) Cable fixed point (1)
h) Cable sealing heads (2)
i) Free rotating head (100 tons)
j) Elongation gauge and recorder

Electrical

a) DC generator (See Table 1)
b) Impulse generator (See Table 1)
c) Laboratory terminations (2) (Table 1)
d) Current heating transformers (Table 1)
e) Low and high pressure oil reservoirs (Table 1)
f) Temperature monitoring & recording equipment (Table 1)
g) Special cable oil (1500 liters)
h) Oil processing equipment (Table 1)

3.2.4 Data to be reported

a) Results of the electrical tests.
b) Bending test tension values and other pertinent observations.
c) Temperature of conductor and sheath during electrical tests.
d) Impulse breakdown test values.
e) Results of dissections of the failed cable/joint.
f) Cable pressure.

3.2.5 Number of Tests

One bending test and one series of electrical tests.

3.2.6 Length of Cable Sample

The bending test sample, including a repair splice, shall be 120 m in length.

3.3 HIGH STRESS TENSILE TEST LI-3

3.3.1 Purpose

The purpose of this test is to demonstrate that the cable and factory joint are mechanically sufficiently strong to withstand much higher tensile forces than those anticipated during laying and retrieval operations. Thus an assessment of the mechanical design safety factor of the cable system can be made.

Electrical tests will not be conducted since no assurance can be given about the preservation of the electrical characteristics of the internal insulation after the cable has been subjected to these high tensile stresses. The significance of this test is that if a length of cable is subjected to a tension significantly higher than the maximum design value , the length will not break but may require replacement.

3.3.2 Test Procedure

Tensile Test

See clause 3.3 of Electra No. 68 for details of the test.

The tensile test shall be performed on a long bed tensile testing machine equipped with a suitable measuring device for recording the maximum tension applied to the cable.

The cable ends shall be provided with suitable heads for application of the tensile load. One head shall be free rotating.

At the start of the test the tension shall be slowly increased to an initial tension value $T_o = 1.85$ tons which has been calculated by the following formula:

$$T_o = 50\ W \qquad \text{tons}$$

where: 50 = length of cable in meters

W = weight of 1 meter of cable in air = 0.037 tons/m (37 kg/m)

After measurement of the length between two index lines marked on the cable (Lo), the tension shall be slowly increased to a value of $T_m = 148$ tons which has been calculated by the following formula:

$$T_m = 2(1.3\ Wh + 6.8) \qquad \text{tons}$$

where: W = weight of cable in water = 0.027 ton/m (27 Kg/m)

h = maximum anticipated depth of deployment = 1915 m

After holding the tension value for 15 minutes, the length between index lines shall be measured (L max) and the revolutions of the free head recorded. The tension shall then be decreased to the initial value (To) and the length between index lines recorded (Lo'). The cycle shall be repeated three times.

Upon completion of the tensile test, two areas of the cable shall be dissected one along the unspliced cable and the other at the factory joint. For engineering information, the cable and joint shall be subjected to selective analysis including a) tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes, registrations, b) damage to lead sheath or reinforcement, and c) condition of conductor, armor and outer covering.

3.3.3 Test and Measuring Equipment

a) Tensile test facility (200 tons)
b) Elongation gauge and recorder
c) Cable mechanical end heads; one head free rotating (150 tons)
d) Load cell & cell housing (200 tons)
e) Cable fixed point (200 tons)
f) Special cable oil (200 liters)
g) Oil processing equipment (Table 1)

3.3.4 Data to be Reported

a) The maximum tension applied to the cable for 15 minutes
b) Values of Lo, Lmax and Lo' for each cycle
c) The calculated ratios:

$$\frac{L_{max} - L_o}{L_o} \quad \text{and} \quad \frac{L_o' - L_o}{L_o}$$

for each cycle

d) Number of revolutions of the free head
e) Results of cable dissections

3.3.5 Number of Tests

One

3.3.6 Length of Cable Sample

50 m

3.4 REPEATED FLEXURE TEST LI-4

3.4.1 Purpose

The purpose of this test is to demonstrate that the lead sheath of the cable can withstand the fatigue stresses that would occur during the construction of an at-sea repair joint under worst sea conditions. Under such a situation, the cable would be repeatedly bent and straightened on the 12 m overboarding sheave due to the pitching of the vessel.

3.4.2 Test Procedure

Repeated Flexure Test

The test shall be performed on a sample of cable without a joint and shall be conducted in a test arrangement as shown in Figure 2.

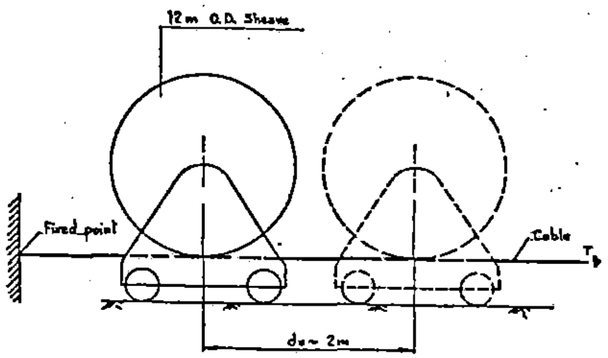


Fig. 2 Repeated Flexure Test
T = Applied Cable-Tension
d = Sheave Horizontal Displacement

The cable shall be attached to a fixed point at one end and to a tensioning device on the other. The horizontal pulling force to be continuously applied to the cable shall correspond to the tension that the cable would experience at the maximum depth at which a repair operation may be conducted on the cable. The maximum depth at which it is considered feasible to effect a repair is considered to be in the order of 600 m. The tensile force is calculated by the following formula:

$$T = 1.15\ (1.3\ Wh + 6.8) \qquad \text{tons}$$

where: W = weight of cable in water
= 0.027 ton/m (27 kg/m)

h = maximum depth at which cable can be repaired, i.e. ~600 m.

In this formula, the numerical coefficient of 1.3 takes into account the presence of an alternating component in the tensile force (100% static ± 30% alternating).

To prevent fatigue of the lead sheath during an actual at-sea jointing operation, a short length of cable would be periodically overboarded thereby moving the flexure point to a new location along the cable. Correspondingly, in this test the 12 m sheave shall be moved back and forth for a distance of approx. 2 m.

On the assumption that the pitching of the vessel will occur approximately once every 10 seconds (0.1 Hz) and also assuming that a new short length of cable will be overboarded once every six hours, the cable lead sheath at discrete points will be subjected to 2160 flexing cycles during the course of the repair operation. The resultant strain on the lead sheath during each of the 2160 flexing cycles on the 12 m sheave is 0.69%. The lead sheath fatigue arising from the alternating component of the tensile force is neglected because the associated strain variation (0.064%) is small when compared to that due to bending.

If the frequency of the test flexures differs from the 0.1 Hz assumed under at-sea conditions, then the number of test cycles N_t to be performed shall be computed by the formula:

$$N_t = 1.25\ N_s \sqrt[3]{\frac{f_t}{f_s}}$$

N_t = number of test cycles

N_s = number of at-sea cycles (assumed 2160)

f_t = frequency of test flexures

f_s = frequency of at-sea cycles (assumed 0.1 Hz)

It is presently considered that a suitable value for f_t is in the range of 0.02 to 0.05 Hz.

The above formula is taken from the Pirelli paper presented at the IEEE 1986 Summer Meeting (reference 1). It also may be derived from formula (6) of the Cable Catenary Study (reference 2).

Cable Dissection

Upon completion of the repeated flexure test, the cable sample shall be physically examined for evidence of mechanical damage to all components particularly the lead sheath. Coupon samples of the lead sheath shall be cut from the section of cable subjected to the flexing action and subjected to metallographic examination in comparison with coupon samples cut from unflexed sections of the cable and with recorded results obtained on coupon samples previously subjected to various degrees of flexing/fatigue.

For engineering information, the cable in the flexed area shall be subjected to selective analysis including a) tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes, registrations, and b) condition of conductor, armor and outer covering.

3.4.3 Test and Measuring Equipment

a) 12 m sheave with trolley
b) Tensile test facility (100 tons)
c) Cable mechanical end heads (150 tons) (2)
d) Load cell
e) Tensile recorder
f) Cable fixing point (100 tons)
g) Free rotating head (100 tons)
h) Elongation gauge and recorder
i) Winches (2)
j) Special cable oil (200 liters)
k) Oil processing equipment

3.4.4 Data to be Reported

a. Number and frequency of flexure cycles
b. Observations during flexure test
c. Results of cable dissection
d. Results of metallographic examination

3.4.5 Number of Tests

One

3.4.6 Length of Cable Sample

120 m

3.5 DETERMINATION OF CRITICAL SPAN LENGTH

3.5.1 Purpose

The purposes of the following tests are to facilitate the determination of the maximum critical span lengths of cable suspensions which are developed when the cable is laid over irregularities on the sea floor and the cable is subjected to tidal and bottom currents.

Since the critical span length of a suspended cable is a function of the current velocity, cable dynamic and static flexural rigidities, cable damping coefficient, mechanical tension of the cable at the sea bottom and weight of the cable in water, it is necessary to conduct two preliminary tests in order to perform the calculations. These tests include determination of static flexural rigidity and determination of dynamic flexural rigidity and dampening coefficient.

3.5.2A <u>Test Procedure - Measurement of Static Flexural Rigidity</u> LI-5

A cable sample shall be suspended horizontally with one end fixed and with a constant vertical force applied to the opposite end as shown in Figure 3. At both ends, the congruence of all cable components shall be maintained by means of suitable end caps and clamping devices. The beam length, l, shall be in excess of the lay length of the armor. A practical value is 2 m.

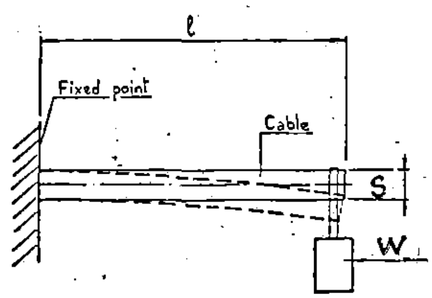


Fig. 3 Static flexural rigidity measurement

S = measured displacement

l = beam length ($\cong$ 2m)

The sag of the free end shall be recorded until a steady state condition is reached. The static flexural rigidity EJs is computed by the formula:

$$EJ_s = \frac{l^3}{S}\left(\frac{P}{3} + \frac{Wl}{8}\right)$$

where: EJ_s = static flexural rigidity

l = length of cable sample

S = beam sag at steady state condition

P = constant vertical force

W = weight of cable per meter

3.5.3A Test and Measuring Equipment

(a) Mechanical testing arrangement as shown in Figure 3.
(b) Cable mechanical end heads (10 tons) (2) suitably configured to maintain the congruence of all cable components.
(c) Equipment for gradual application of constant vertical force.
(d) Recording device for measurement of cable end displacement in order of some tens of mm. (Displacement transducer)

3.5.4A Data to be Reported

(a) Cable vertical force and end displacement
(b) Cable length and weight

3.5.5A Number of Tests

Three

3.5.6A Length of Cable Sample

Included in 80 m sample of 3.5.6 B.

3.5.2B TEST PROCEDURE - MEASUREMENT OF DYNAMIC FLEXURAL RIGIDITY AND DAMPENING COEFFICIENT LI-6

A cable sample shall be suspended between two fixed points as shown in Figure 4.

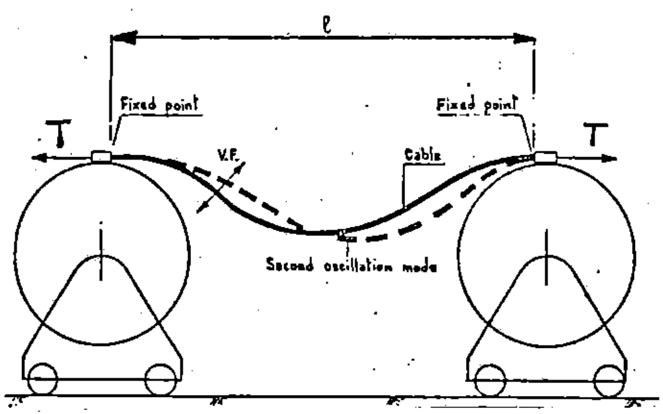


Fig. 4 Measurement of Flexural Rigidity Test and Damping Coefficient

ℓ = Span Length
V.F. = Vibrating Force
T = Constant Pulling Force

The cable span between the two sheaves shall be 25 to 30 m in length. The cable shall be subjected a constant pulling tension such as to produce a sag of 1.3 m in the center of the span. The value of 1.3 m has been determined experimentally to facilitate measurements at the given span length with the cable under a practical value of pulling tension.

A vibrating force shall be applied to the cable at a quarter of the span length and accelerometers shall be fixed to the cable to monitor the configuration assumed by the vibrating cable. The frequency of the vibrating force which imparts to the cable the second oscillating mode shall be used to calculate the dynamic flexural rigidity of the cable by means of the following formula:

$$EJ_d = \frac{l^2 \quad (ml^2 \, f^2 - T)}{4\pi^2}$$

where: EJ_d = dynamic flexural rigidity

l = length of cable span

m = mass of cable

f = frequency of the vibrating force at the second cable oscillating mode

T = constant pulling tension

Using the same test arrangement, the damping coefficient shall be determined as the mean value obtained by a number of "decay tests" performed by stopping the vibrating force in the range of 0.5 - 1.5 Hz.

The above formula is derived from formula (7) of the paper "Mathematical Analysis of Transmission Line Vibration" (reference 4) by substituting (a) 2 f for the resonance pulsations Wr and (b) r = 2 for the mode of oscillation.

3.5.3B <u>Test and Measuring Equipment</u>

a) Mechanical testing arrangement as shown in Figure 4. The sheaves are 3 m in diameter.
b) Mechanical pulling machine.
c) Cable mechanical end heads. (10 tons) (2)
d) Vibration inducing equipment.
e) Accelerometer.
f) Trolleys for sheaves (2)
g) Fixed points (2)

3.5.4B Data to be Reported

a) Mass of cable
b) Span length & sag
c) Cable tension
d) Frequency of vibrating force which induces the second oscillating mode to the cable
e) Damping coefficient

3.5.5B Number of Tests

One

3.5.6B Length of Cable Sample

80 m

3.5.7 Calculation of Critical Span Lengths

After performing the preliminary tests to measure the static and dynamic flexural rigidity and dampening coefficient, the maximum permissible span length for both tidal oscillations and vortex shedding can be calculated. The bottom current speed from actual current meter measurements and the bottom tension of the cable must be known or assumed.

The calculations shall be made in accordance with the Cable Catenary Study (reference 2) based on the technical papers (references 4, 5, 6 and 7).

3.6 CABLE OSCILLATION TEST UNDER SIMULATED TIDAL ACTION LI-7

3.6.1 Purpose

The purpose of this test is to demonstrate the ability of the cable suspended between two outcrops to withstand tidal movements without experiencing damage to the lead sheath which would limit its life to less than 30 years.

3.6.2 Test Procedure

See Figure 5 for a schematic diagram of the test set-up:

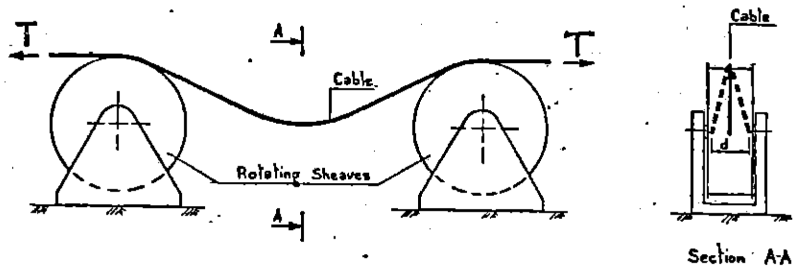


Fig. 5 Cable Oscillations Under Tidal Currents Test

T = Pulling Force

d = Required Displacement

A cable sample shall be suspended between two sheaves with a spacing less than the shortest critical span length (See 3.5.7) and pulled with a 3 ton force. The cable shall be made to oscillate with a displacement to the central point of the cable such that the maximum strain at the fixed points will be the same as the strain due to sea current action.

The maximum strain $\Delta\varepsilon_1$ (peak to peak) in the sea bottom condition is computed with formula (7) of the Catenary Study. The maximum strain $\Delta\varepsilon_2$ (peak to peak) under test conditions is computed according to the formula:

$$\Delta\varepsilon_2 = \frac{24\ D_s d}{l^2}$$

where: d = displacement imposed to the mid point of the cable (peak to peak)

D_s = lead sheath diameter

l = span length

By equating the two strains, the peak to peak test displacement is calculated with the following formula:

$$d = \frac{l^2}{24\ D_s} \cdot \Delta\varepsilon_1$$

Tides have a frequency of 2 cycles per day. To reduce the testing time, the test frequency shall be accelerated to one cycle per second. The test shall be continued either to failure as evidenced by leakage of oil between the lead sheath and polyethylene jacket or to five times the number of cycles corresponding to a 30 year life (approx. 45 days testing) as computed by the following formula, whichever comes first:

$$N_t = N_s \sqrt[3]{\frac{f_t}{f_s}}$$

where: N_t = number of test cycles corresponding to 30 year life

N_s = number of cycles at sea corresponding to 30 year life = 22,000

f_t = test frequency = 1 cycle/sec = 86,400 cycles/day

f_s = frequency at sea = 2 cycles/day

A physical examination of the sample, shall be conducted for evidence of mechanical damage (leakage of oil) of the lead sheath.

If the test is terminated prior to failure, coupon samples of the lead sheath shall be cut from the section of cable subjected to the flexing action and subjected to metallographic examination in comparison with coupon samples cut from unflexed sections of the cable and with recorded results obtained on coupon samples previously subjected to various degrees of flexing/fatigue.

3.6.3 Test and Measuring Equipment

a) Rotating sheaves 3 m in diameter (2)
b) Cable mechanical end heads (10 tons) (2)
c) Mechanical pulling machine for applying 3 tons of force to the cable (2)
d) Vibrating device capable of applying a 1 cycle per second oscillatory movement to the cable
e) Load cell (2 tons) for measuring the tension on the cable
f) Device for measuring the oscillations of the cable
g) Trolleys for sheaves (2)
h) Fixed points (clamps) (2)

3.6.4 Data to be Reported

a) Tensile force on the cable
b) Number of oscillations to which cable was subjected
c) Results of examination of the lead sheath for mechanical damage
d) Results of metallographical examination

3.6.5 Number of Tests

One

3.6.6 Length of Cable Per Test

80 m

3.7 LEAD SHEATH FATIGUE TEST LI-8

3.7.1 Purpose

The purpose of this test is to determine the fatigue life of lead alloy E, used for the cable sheath, under the conditions of the cable subjected to tidal action. The test results obtained after one year on 20 full size cable samples under reasonably accelerated test conditions will confirm the validity of the Pirelli formula for determining the life expectancy of Alloy E lead sheath corresponding to a given strain change and cycle rate at a given failure probability level. The Pirelli formula can then be used to determine the life expectancy of Alloy E lead sheath on Cable No. 116 under tidal action (not less than 30 years).

3.7.2 Test Procedure

A testing machine comprised of 20 modular units is designed to test 20 cable samples at one time.

See Figure 6 for a schematic diagram of test set-up for one cable sample.

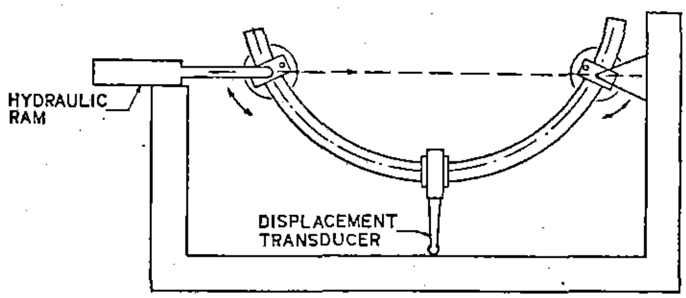


FIG.6 Lead Sheath Fatigue Test

The cable samples, each approximately 3 meters in length, are predeformed to a circular arc and each clamped by means of two swivel cleats. One cleat is fixed and the other is capable of being moved in the direction along the chord joining the extremities of the circular arc by means of a hydraulic ram.

The motor unit is used to obtain the required cable movements with the required cycle rate. To this end, both the amount of cable displacement along the chord and its speed (related to the cycle rate) can be suitably adjusted. The initial cable sag and the amount of its variation are adjusted during the setting-up of the testing equipment to obtain a strain variation of 1.5×10^{-3} on the lead sheath. A test frequency of 3 cycles per hour shall be employed to achieve the desired test duration of one year.

The test shall be conducted for a time duration for 50% of the cable samples to fail plus 15 days.

The congruence of armor, lead sheath and conductor shall be achieved by means of suitable cable end heads.

Failure of the cable lead sheath during the test shall be indicated by drop of the internal oil pressure caused by the oil leak immediately following the sheath failure.

3.7.3 Test and Measuring Equipment

(a) Testing machine comprised of 20 modular units
(b) Actuator system for testing machine
(c) Cable mechanical end heads (40) suitably designed to maintain congruence of all cable components
(d) Measuring/recording device for measuring number and amount of cable displacements in the range of 5 mm for the chord and 20 mm for the sag (displacement transducer) (20)
(e) Recording device for measuring/recording internal oil pressure (20)
(f) Special cable oil
(g) Oil processing equipment

3.7.4 Data to be Reported

(a) Cable sample displacements (chord and sag)
(b) Internal oil pressure
(c) Number of cycles (Cable sample displacements) to each failure

3.7.5 Number of Tests

Twenty tests carried out simultaneously on 20 cable samples.

3.7.6 Length of Cable Per Test

3 m; total of 60 m of cable

3.8 FRICTION FORCE TEST LI-9

3.8.1 Purpose

The purpose of this test is to determine the friction force exchanged between the conductor and armor of the cable with minimal compressive force exerted by the armor on the underlying cable components.

This test shall be performed on "as manufactured" cable and on a cable previously subjected to a tension of 85 tons.

3.8.2 Test Procedure

A 10 m length of cable shall be tensioned such that an external load shall be applied to the conductor at one end and a restraining load shall be applied to the armor at the opposite end. The conductor shall have an increasing tensile load applied. The value of the tensile load (pulling force) just prior to displacement of the conductor shall be recorded.

3.8.3 Test and Measuring Equipment

(a) Cable mechanical end head suitable for applying load to the conductor.
(b) Cable mechanical end head suitable for applying a restraining load to the armor while not transmitting a compressive load to other cable components.
(c) Mechanical pulling machine for applying increasing load to the conductor (100 tons).
(d) Load cell (2 tons)
(e) Recording device

3.8.4 Data to be Reported

Value of applied conductor tensile load just prior to the displacement of the conductor with respect to the armor.

3.8.5 Number of Tests

Four; one test per each of three cable samples from "as manufactured" cable and one test on a cable sample from the unbent length of cable subjected to the Bending Test in the Bending and Electrical Test LI-2 (3.2).

3.8.6 Length of Cable Per Test

10 m

3.9 CRUSHING TEST LI-10

3.9.1 Purpose

The purpose of this test is to determine the maximum withstand crushing force for the cable and to permit calculation of the coefficient of friction of the cable as a function of the crushing force.

3.9.2 Test Procedure

See Figure 7 for a schematic diagram of the test set-up:

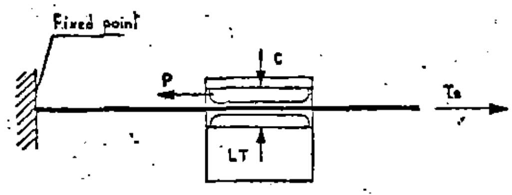


Fig. 7 Crushing Test

Te = Constant pulling force
C = Crushing force
P = Force pulling the LT simulating device
LT = Linear Tensioner simulating device

A cable sample shall be tensioned with a constant pulling force of 85 tons and a linear tensioner simulating device shall be applied to the cable. The device shall apply a crushing force to the cable of 3 tons/m while the tensioner is pulled with increasing force. The pulling force that produces a movement of the device with respect to the outer serving or of the outer serving with respect to the armor shall be recorded. The test shall be repeated at increased crushing forces of 5 and 7 tons/m at different points along the cable and the pulling forces similarly recorded. The sample shall then be dissected for visual examination of the tape shields and insulation structure where the crushing forces have been applied. Specifically, the cable shall be subjected to selective analysis including a) tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes, registrations, b) damage to lead sheath or reinforcement, c) ovalization, d) deformation of polyethylene jacket, and e) condition of armor and outer covering.

3.9.3 Test and Measuring Equipment

a) Hydraulically operated linear tensioner simulating device
b) Cable mechanical end heads (150 tons) (2)
c) Tensile test facility
d) Load cell (20 tons)
e) Recorder
f) Cable fixed point (100 tons)
g) Free rotating head (100 tons)
h) Special cable oil (100 liters)
i) Oil processing equipment

3.9.4 Data to be Reported

a) The forces required to produce a movement of the linear tensioner simulating device with respect to the cable outer covering or of the outer covering with respect to the armor at crushing forces of 3, 5 and 7 tons/m respectively. The location at whch movement occurred shall be identified.

b) Results of visual examination of the tape shields and insulation structure of the cable where the crushing forces were applied and determination of maximum withstand crushing force.

c) Coefficient of friction calculated from the following formula:

$$f = \frac{T}{F}$$

where: f = coefficient of friction

T = maximum pulling force on the linear tensioner simulating device before displacement occurred.

F = crushing force

3.9.5 Number of Tests

One

3.9.6 Length of Cable Sample Per Test

60 m

3.10 SLEEVING TEST LI-11

3.10.1 Purpose

The purpose of the sleeving test is to verify the congruence of the cable components (conductor, armor, etc.), during deployment and retrieval operations using a linear tensioner.

3.10.2 Test Procedure

See Figure 8 for a schematic diagram of the test set-up:

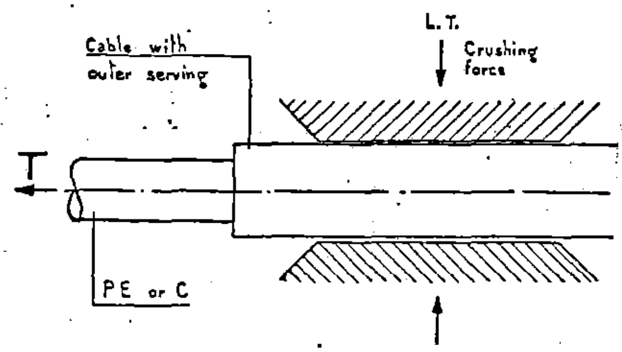


Fig. 8 Sleeving Test

T = Pulling Force
PE = Polyethilene jacket
C = Conductor

A cable sample shall be inserted in the linear tensioner simulating device and the maximum permissible crushing force determined in the Crushing Test (3.7) shall be applied. With this crushing force applied, the conductor alone shall be pulled with an increasing force. The value of the maximum pulling force before displacement of the conductor shall be recorded. The test shall be repeated pulling the conductor, lead sheath and polyethylene jacket as a unit. The two values obtained shall be compared with the computed forces at a pulling tension of 85 tons reduced by the ratio between the lengths of the simulating device and the length of the actual linear tensioner.

3.10.3 Test and Measuring Equipment

a) Hydraulically operated linear tensioner simulating device
b) Cable pulling heads, one designed for pulling the conductor; the second for attachment to the conductor, lead sheath and polyethylene jacket (5 tons) (4)
c) Tensile test facility with a suitable capacity
d) Load cell (20 tons)
e) Free rotating head (100 tons)
f) Recorder

3.10.4 Data to be Reported

a) Pulling tension to produce displacement of the conductor
b) Pulling tension to produce displacement of the conductor, lead sheath and polyethylene jacket as a unit
c) Percent increase of each of above values compared to the ratio between the length of the simulating device to the length of the actual tensioner multipled by 85 tons

3.10.5 Number of Tests

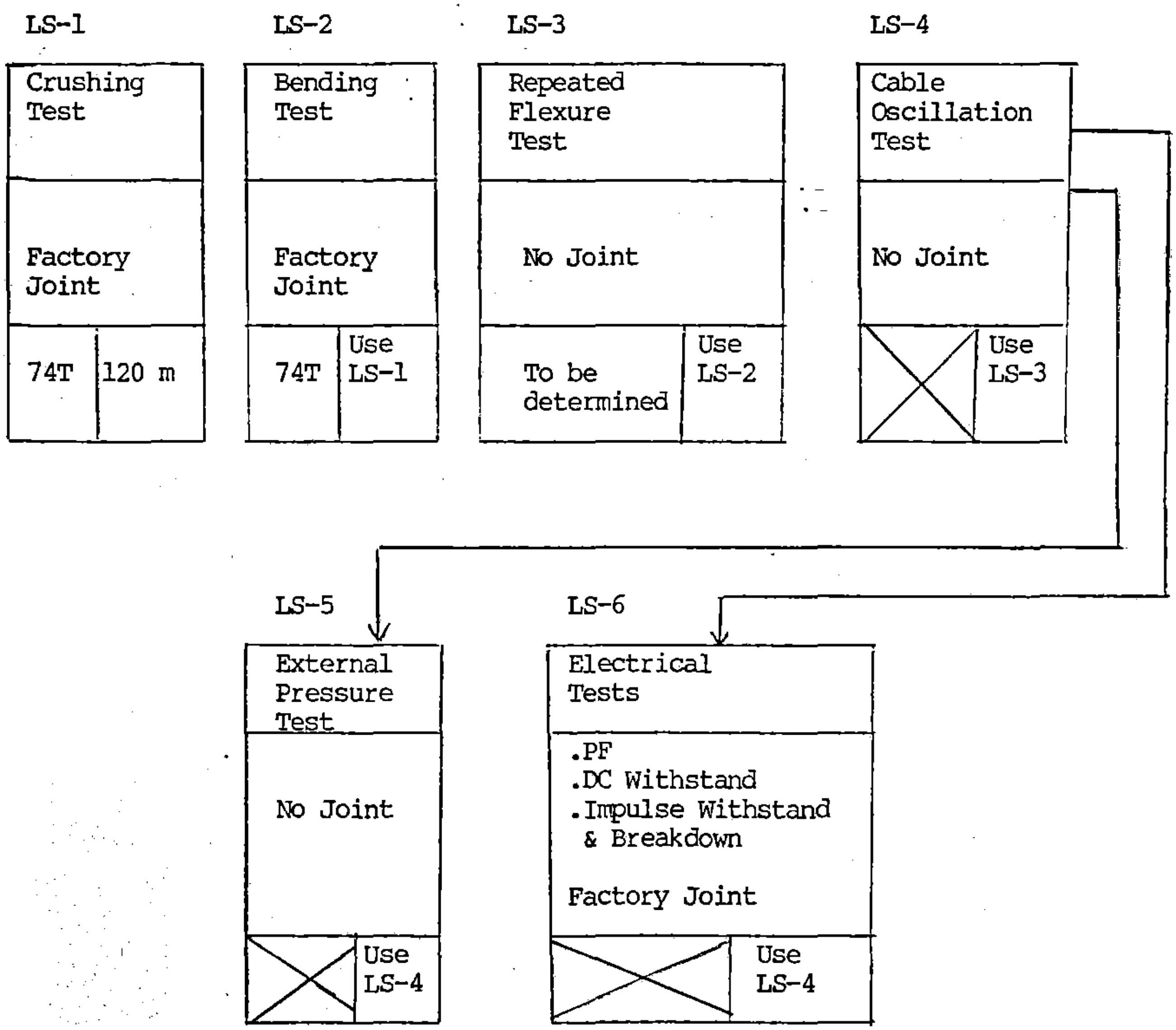
Two

3.10.6 Length of Cable Sample Per Test

40 m

LABORATORY SEQUENCE TESTS

SUMMARY OF LABORATORY SEQUENCE TESTS



4.0 SEQUENCE TEST PROGRAM

4.1 SEQUENCE TESTS

4.1.1 Purpose

The purpose of this test is to demonstrate that the cable and factory joint can withstand the cumulative mechanical stresses arising from a sequence of crushing, bending, repeated flexure and tidal movements simulating cable deployment, retrieval, repair and operation subjected to tidal movements and exhibit satisfactory mechanical and electrical characteristics.

4.1.2 Test Procedure

The following tests shall be performed in sequence on a cable sample including a factory joint: Crushing Test, Bending Test, Repeated Flexure Test and Cable Tidal Oscillation Test. On completion of these tests, the cable shall be divided into two lengths. The shorter length shall be subjected to the External Pressure Withstand Test; the remaining length shall be subjected to electrical tests including Impulse Withstand Test. The impulse voltage shall be increased to breakdown. The cable/joint in the vicinity of the failure and other critical sections of the cable shall be dissected and examined for mechanical damage.

4.1.2.1 CRUSHING TEST LS-1

The device employed for the Crushing Test in 3.7.3 shall be applied to a straight length of cable (Figure 6) and pulled with a force given by the following formula:

$$P = T \cdot \frac{L_d}{L_t}$$

where T = 74 tons (4.2.2)

L_d = length of linear tensioner simulating device

L_t = length of actual linear tensioner

P = pulling force to be applied to the test cable

The crushing force in this test shall be the maximum withstand crushing force determined in 3.7.

4.1.2.2 BENDING TEST LS-2

This test shall be performed employing the same test procedure as for 3.2.2 excluding the electrical tests. The tensile force applied to the cable shall be 74 tons calculated employing the following formula:

$$T = 1.3\ Wh + 6.8 = 74 \text{ tons}$$

where W and h are as defined previously.

4.1.2.3 REPEATED FLEXURE TEST LS-3

This test shall be performed in the same manner as described previously (3.4.2). The jointed section of the cable length shall not be subjected to this test.

The tensioning force shall be computed employing the following formula:

$$T = 1.3\ Wh' + 6.8$$

where: W = weight of cable in sea water as defined previously

h' = the maximum water depth feasible for cable retrieval and repair as determined in the Cable Repair Rationale activity

4.1.2.4 CABLE OSCILLATION TEST UNDER SIMULATED TIDAL ACTION LS-4

This test shall be performed as described previously (3.6.2) on the non-jointed section of cable. The test shall be terminated after the number of cycles (N_t) corresponding to 30 year life.

4.1.3 Test And Measuring Equipment

The test and measuring equipment for sequence tests 4.1.2.1, 4.1.2.2, 4.1.2.3 and 4.1.2.4 shall be same as indicated previously for the respective tests.

4.1.4 Number of Tests

One per each of sequential tests from 4.1.2.1 through 4.1.2.4.

4.1.5 Length of Cable Sample Required for the Sequences Tests

120 m

4.2 EXTERNAL WATER PRESSURE WITHSTAND TEST LS-5

4.2.1 Purpose

The purpose of this test is to demonstrate that the cable can successfully withstand the maximum difference between the external water head pressure and the internal oil head pressure to which the lead sheath is exposed during deployment and in service. This maximum differential pressure across the lead sheath will be experienced in case of loss of the additional oil pressure provided by the oil pumping stations installed at the cable ends.

4.2.2 Test Procedure

See paragraph 3.4 of Electra No. 68 for details of the test. The cable sample shall be selected as indicated in 4.1.2.

The cable sample, suitably sealed at the ends by means of caps, shall be introduced into a pressure pipe and subjected to a test pressure for 48 hours. The cable shall be internally filled with oil maintained at atmospheric pressure. The test pressure shall be 20 percent higher than the maximum difference between outer water pressure and internal pressure to which the lead sheath is exposed during deployment or during service.

The test pressure shall be 1.1 MPa (11 bars) calculated employing the following formula:

$$P = 1.2\ (\rho_s - \rho_o)\ \frac{h}{1000} \quad \text{MPa}$$

where: ρ_s = density of sea water = 10.35 kN/m^3

ρ_o = density of cable oil = 9.87 kN/m^3

h = maximum anticipated depth of deployment

= 1915 m

4.2.3 Test and Measuring Equipment

a) 6 inch (152 mm) inside diameter 20 atm rated steel pipe 5 m in length
b) Oil pump with output pressure capability of at least 1.1 MPa (11 bars)
c) Pressure transducers of suitable pressure range (2)
d) Pressure recorder 3 channels
e) Cable end caps (2)
f) Vacuum pump

4.2.4 Data To Be Reported

a) Test pressure
b) Time of application
c) Condition of lead sheath after performance of test, e.g. creases, shape irregularity, etc.
d) Overall diameter of the cable
e) Difference between maximum and minimum diameter (ovalization)

4.2.5 Number of Tests

One

4.2.6 Length of Cable Required

2 m. To be taken from the 120 m length subjected to the Sequence Tests.

4.3 ELECTRICAL TESTS LS-6

The electrical tests described in 3.1 shall be performed on the longer part of the cable including the joint after completing the sequence tests of 4.1.2.1, 4.1.2.2, 4.1.2.3 and 4.1.2.4.

4.3.1 Data to be Reported

4.3.1.1 Electrical Tests

Test Conditions - Temperature of conductor and Δt between conductor and sheath

Power Factor - Comparison with 3.1

DC Withstand Test - Pass or fail 600 kV for 15 minutes

Impulse Withstand Test - Pass or fail 775 kVp

Impulse Breakdown Test - Breakdown voltage comparison with 3.1

4.3.1.2 Dissection and Analysis

For engineering information the cable and joint shall be subjected to selective analysis including a) tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes, registrations, b) damage to lead sheath or reinforcement, c) ovalization, d) deformation of polyethylene jacket, and e) condition of armor and outer covering.

TABLE 1

GENERAL TESTING EQUIPMENT

Power Factor Bridge:	Messwandler Transformer Bridge
Impulse Generator:	2000 KV min. 200 KJ min.
DC Generator:	1000 KV min. 5 mA min.
Current Heating Transformers:	50 KVA Capacity min.
Tensile Test Machine: (200 Tons Capacity)	High Pressure Hydraulic Cylinder Type Equipped With Instruments For Recording Tension, Torque Moment, Elongation & Rotation
Temperature Monitoring and Recording Equipment	-
Laboratory Terminations:	Conventional High Voltage AC Sealing Ends Rated: 500 kV - Loading Cycle & Polarity Reversals 230 kV - Impulse Tests 400 kV - DC Tests
Low and High Pressure Oil Reservoirs:	
A2/120 Reservoirs (24)	Non-pressurized 120 Liters
P2/25 Reservoirs (18)	Pressurized 25 Liters
Oil Processing Equipment:	
Degassifier	600 Liters per Hour
Oil Pumping Plant	1000 kPa (10 bars)
Oil Draining Vacuum Pumps (2)	-
Oil Filtration Equipment	-
Small Trolleys (80)	-
Ramps (4)	-
Heat Insulation (200 m)	-

REFERENCES

1. "The Fatigue Life of Lead Alloy E as a Sheating Material for Submarine Power Cables", by P. Anelli, F. Donazzi, W. G. Lawson

2. Hawaii Deep Water Cable (HDWC) Program Revised Cable Catenary Study Dated October 3, 1985 Prepared by Pirelli Cable Corporation for the Ralph M. Parsons Company

3. AEIC CS4-79 Specifications for Impregnated-Paper-Insulated Low and Medium Pressure Self Contained Liquid Filled Cable. (Seventh Edition)

4. "Mathematical Analysis of Transmission Line Vibration" by R. Claren, G. Diana, I.E.E.E. Trans. Vol. PAS-88, 1969, pp. 1741-1771.

5. "Induced Oscillation on a Cylinder at High Reynold's Number Due to Vortex Shedding" by F. Donazzi, G. Diana, M. Falco, Peng Guoxun, NHL International Symposium, Norwegian Institute of Technology, 1981, pp. 307-325.

6. "Dynamic Response of an Undersea Cable to a Turbulent Flow", by G. Diana, G. Mimmi, G. X. Peng, L'Energia Elettrica, 1982, pp. 234-242.

7. "Dynamic Strain Distribution on Loaded Stranded Cables", by R. Claren, G. Diana, I.E.E.E. Trans., Vol. PAS-88, 1969, pp. 1678-1690.

APPENDIX A

QUALIFICATION TEST

SUMMARY OF QUALIFICATION TESTS

Q-1

Bending & Electrical Test	
.Load Cycle & Polarity Reversal .Impulse Withstand and Breakdown	
No Joint	
85T	included in Q-2

Q-2

Bending & Electrical Test	
.Load Cycle & Polarity Reversal .Impulse Withstand and Breakdown	
Factory Joint	
85T	120 m

Q-3

Bending & Electrical Test	
.Load Cycle & Polarity Reversal .Impulse Withstand and Breakdown	
Repair Joint	
85T	120 m

Q-4

Tensile Test	
No Electrical	
Repair Joint	
85T	50 m

Q-5

External Water Pressure Test	
No Electrical	
No Joint	
1.1 MPa	5 m

Q-6

Internal Pressure Test	
No Electrical	
No Joint	
5 MPa	15 m

APPENDIX A

A. QUALIFICATION TESTS

A.1 BENDING AND ELECTRICAL TESTS Q-1, Q-2 & Q-3

A.1.1 Purpose

The purpose of this test is to demonstrate the electrical characteristics of the cable and to show that the electrical characteristics are not impaired by bending under tension simulating the forces that occur during both deployment and recovery operations.

A.1.2 Test Procedure

a) Bending Test

The mechanical set-up for performing the bending test shall be in accordance with Figure 1 of Electra No. 68. Alternatively, the bending of the cable shall be accomplished as shown in Figure 1:

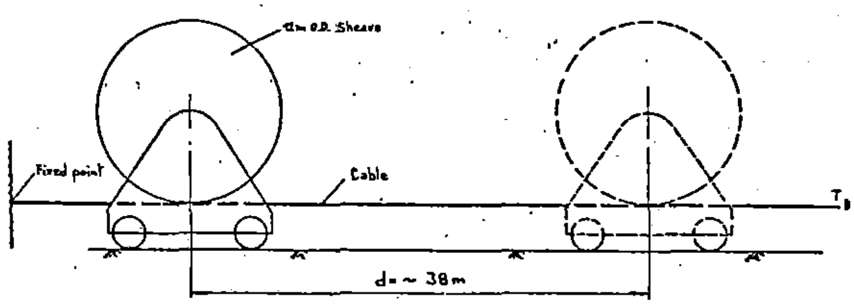


Fig. 1 Bending Test
T= Applied Cable Tension
d= Sheave Horizontal Displacement

The cable ends shall be secured with mechanical heads that are designed to join all metal components of the cable in such a manner as to provide the same distribution of tensile load as will be experienced during cable deployment.

See paragraph 3.2 of Electra No. 68 for details of bending test. The oil pressure at the highest position shall be adjusted to 700 kPa (7 bars). This oil pressure is sufficiently high to closely approach the electrical properties of the cable at its operating pressure of 25 to 30 bars while facilitating the performance of the test. Two bending tests shall be conducted. One test shall be performed on a length of cable containing a factory joint. The second test shall be performed on a length of cable containing a repair joint. Each length of cable shall be wound on a drum having a diameter of 12 m which will be the diameter of the overboarding sheave installed on the cable laying ship. During the bending test, the cable shall be subjected to a mechanical tension of 85 tons calculated using the following formula:

$$T = 1.15\ (1.3\ Wh + 6.8) \quad \text{tons}$$

where: W = weight of cable in water
water = 0.027 ton/m (27 kg/m)

h = maximum anticipated depth of deployment
= 1915 m

NOTE: The above formula, compared to the formula in Electra No. 68, incorporates a higher bottom tension due to the greater difficulty in controlling bottom tension at the greater deployment depths and a factor of safety. The 85 tons tension calculated by the above formula corresponds to a deployment depth of 2307 m calculated by the formula in Electra No. 68.

Although the maximum depth at which a repair joint can be made will be in the order of 1/3 of h, it is considered desirable to demonstrate that the repair joint can withstand the same tensile forces as the cable and factory joint.

b) Electrical Test

After the bending test, the cable length containing the factory joint shall be divided into two cable lengths, one containing the factory joint. The resultant three cable lengths, one, cable only, the second cable with factory joint and the third cable with repair joint, designated Q-1, Q-2 and Q-3, respectively, shall be subjected to the following electrical tests:

Load Cycle and Polarity Reversal Test

This test, comprising 30 loading cycles, shall be performed in accordance with Clause 10 of Electra No. 72. A loading cycle shall consist of 8 hours heating, at the end of which the conductor temperature shall be not less than 90°C (maximum rated temperature plus $5^{o}C$) and the temperature across the insulation shall be 11K (maximum design value for this cable design and application). The 30 loading cycles are divided into 3 tests of 10 cycles each:

The first 10 loading cycles shall be carried out with a positive dc voltage of 600 kV (2 Uo) applied between conductor and sheath.

The second 10 loading cycles shall be carried out with a negative dc voltage of 600 kV (2 Uo) applied between conductor and sheath.

The third 10 loading cycles shall be carried out with a dc voltage of 450 kV (1.5 Uo) applied between conductor and sheath. Starting with positive voltage, the voltage polarity shall be reversed every 4 hours and one reversal shall coincide with the cessation of loading current in every loading cycle. The recommended time duration for a polarity reversal is maximum of 2 minutes, however, the time duration may be extended to 10 minutes maximum if the time constant is long.

Impulse Withstand Test

This test shall be conducted in accordance with Clause 11, sub-paragraph 11.1, of Electra No. 72 and the referenced IEC Publication 230. The oil pressure at the highest position of the installation shall be adjusted to a value of 700 kPa (7 bars). The conductor shall be current loaded to a temperature of $90^{o}C$ (maximum rated temperature plus $5^{o}C$). The temperature across the insulation shall be 11K (maximum design value for this cable design and application).

A negative d.c. voltage equal to 300 kV shall be applied between conductor and sheath for at least 2 hours. After this time and without disconnecting the d.c. voltage, 10 positive lightning impulses shall be superposed on 300 kV. d.c.

After having deenergized the cable, a positive d.c. voltage of 300 kV shall be applied between conductor and sheath for at least 2 hours. Then 10 negative lightning impulses shall be superposed on + 300 kV d.c.

The impulse shall be such that the peak value measured between cable conductor to ground is equal to 775 kV. The time between each impulse shall not be shorter than 2 min. No breakdown shall occur.

Test circuits suitable to obtain the superposition of an impulse on a d.c. voltage are shown in Figure 1 and 2 of Electra No. 72.

For engineering information, the cable shall be dissected in the region of the breakdown area to determine the casue of failure and the failure path. In addition, should the failure not occur within the joints, the joints shall be dissected and a detailed examination of all components shall be conducted and recorded. Specifically the cables and joints shall be subjected to selective analysis including a) tape shield and insulating tape structure, e.g. uniformity of gaps, creases, torn tapes, registrations, b) damage to lead sheath or reinforcement, c) ovalization, d) deformation of polyethylene jacket, and e) condition of conductor armor and outer covering.

A.1.3 Test and Measuring Equipment

Mechanical

a) 12 m sheave with trolley
b) Tensile test facility (100 tons)
c) Cable mechanical end heads (4)
d) Load cell (100 tons)
e) Tensile recorder
f) Low and high pressure oil reservoirs (Table 1)
g) Cable fixed point (1)
h) Cable sealing heads (4)
i) Free rotating head (100 tons)
j) Elongation gauge and recorder

Electrical

a) DC generator (See Table 1)
b) Impulse generator (See Table 1)
c) Laboratory terminations (6) (Table 1)
d) Current heating transformers (Table 1)
e) Tensile recorder
f) Low and high pressure oil reservoirs (Table 1)
g) Temperature monitoring and recording equipment (Table 1)
h) Special cable oil (5000 liters)
i) Oil processing equipment (Table 1)

A.1.4 Data to be Reported

a) Results of the electrical tests
b) Bending test tension values and other pertinent observations
c) Temperature record of conductor and sheath during electrical tests
d) Impulse breakdown test values for the cable lengths
e) Results of dissection of the failed cable/joint
f) Cable oil pressure

A.1.5 Number of Tests

A total of two bending tests and three electrical tests will be performed.

A.1.6 Length of Cable Sample per Test

Each bending test sample, including a factory and repair joint, respectively, shall be 140 m in length.

A.2 TENSILE TEST Q-4

A.2.1 Purpose

The purpose of this test is to evaluate the basic mechanical properties of the cable and repair joint when subjected to tensile forces more severe than the maximum forces expected to be experienced during cable deployment.

A.2.2 Test Procedure

See paragraph 3.3 of Electra No. 68 for details of the test.

The tensile test shall be performed on a long bed tensile testing machine equipped with a suitable measuring device for recording the maximum tension applied to the cable.

The cable ends shall be provided with suitable heads for application of the tensile load. One head shall be free-rotating.

At the start of the test, the tension shall be slowly increased to 1.85 tons calculated by the following formula:

$$T_o = 50\ W \ \text{tons}$$

where: 50 is the length of the cable in meters

W = weight of 1 meter of cable in air
= 0.037 tons/m (37 kg/m)

After measurement of the length between two index lines marked on the cable (Lo), the tension shall be slowly increased to 85 tons (see 3.2.2) and maintained at this value for 15 minutes. Then the length between index lines shall be measured (L max) and the revolutions of the free head recorded. The tension shall then be decreased to the initial value To and the length between index lines recorded (Lo'). The cycle shall be recorded three times.

A.2.3 Test and Measuring Equipment

a) Tensile test facility (100 tons)
b) Tensile recorder
c) Cable mechanical end heads; one head free rotating

d) Cable fixed point (100 tons)
e) Load cell and cell housing (100 tons)
f) Elongation gauge & recorder
g) Special cable oil (200 liters)
h) Oil processing equipment

A.2.4 Data to be Reported

a) The maximum tension applied to the cable for 15 minutes
b) Values of Lo, Lmax and Lo' for each cycle
c) The calculated ratios:

$$\frac{Lmax-Lo}{Lo} \quad \text{and} \quad \frac{Lo'-Lo}{Lo}$$

for each cycle
d) The revolutions of the free head
e) Results of visual examination of the cable sample

A.2.5 Number of Tests

One

A.2.6 Length of Cable Sample per Test

50 m

A.3 EXTERNAL WATER PRESSURE WITHSTAND TEST Q-5

A.3.1 Purpose

The purpose of this test is to demonstrate that the cable can successfully withstand the maximum difference between the external water head pressure and the internal oil head pressure to which the lead sheath is exposed during deployment and in service. This maximum differential pressure across the lead sheath will be experienced in case of loss of the additional oil pressure provided by the oil pumping stations installed at the cable ends.

A.3.2 Test Procedure

See paragraph 3.4 of Electra No. 68 for details of the test. A cable sample, suitably sealed at the ends by means of caps, shall be introduced into a pressure pipe and subjected to a test pressure for 48 hours. The cable shall be internally filled with oil maintained at atmospheric pressure. The test pressure shall be 20 percent higher than the maximum difference between outer water pressure and interval pressure to which the lead sheath is exposed during deployment or during service.

The test pressure shall be 1.1 MPa (11 bars) calculated employing the following formula:

$$P = 1.2 \; (\rho_s - \rho_o) \; \frac{h}{1000} \qquad \text{MPa}$$

where: ρ_s = density of sea water = 10.35 kN/m^3

ρ_o = density of cable oil = 9.87 kN/m^3

h = maximum anticipated depth of deployment
= 1915 m

A.3.3 Test and Measuring Equipment

a) Pressure tube
b) Pressurizing apparatus
c) Pressure transducers of suitable pressure range (2)
d) Pressure recorder 3 channel
e) Cable sealing heads, Type B (2)
f) Vacuum pump

A.3.4 Data to be Reported

a) Test pressure
b) Time of application
c) Condition of lead sheath after performance of test, e.g. creases, shape irregularity, etc.
d) Overall cable diameter
e) Difference between maximum and minimum diameter (ovalization)

A.3.5 Number of Tests

One

A.3.6 Length of Cable Sample Per Test

5 m

A.4 INTERNAL PRESSURE WITHSTAND TEST Q-6

A.4.1 Purpose

The purpose of this test is to demonstrate that the cable can successfully withstand the maximum pressure difference between the internal oil pressure and the external water pressure that can exist under all possible operating conditions. The maximum pressure difference can exist across the lead sheath with the cable in shallow water or on land with the oil pump operating at maximum pressure.

A.4.2 Test Procedure

See paragraph 3.5 of Electra No. 68 for details of the test. A sample of finished cable, with the tapes of the mechanical reinforcement jointed (welded or soldered) in accordance with the manufacturers standard practice, shall be used for the test. Both cable ends shall be fixed to prevent rotation.

The cable sample shall be subjected for 24 hours to an internal pressure of 5 MPa determined from the following formula:

$$P' = 1.5\,P'o + 0.5 \quad \text{MPa}$$

where: P'o = maximum pressure difference to which the lead sheath will be subjected in service = 3 MPa (30 bars)

A.4.3 Test and Measuring Equipment

a) Pressurizing apparatus
b) Pressure transducer
c) Pressure recorder, 2 channel
d) Cable sealing heads Type C (2)
e) Anti-twist clamps (2)

A.4.4 Data to be Reported

a) Test pressure
b) Time of application
c) Condition of reinforcing tapes; e.g. evidence of broken tapes
d) Evidence of oil leaks or damage to the lead sheath

A.4.5 Number of Tests

One

A.4.6 Length of Cable Sample Per Test

15 m

TABLE Q-1

GENERAL TESTING EQUIPMENT

Power Factor Bridge:	Messwandler Transformer Bridge
Impulse Generator:	2000 KV min. 200 KJ min.
DC Generator:	1000 KV min. 5 mA min.
Current Heating Transformers:	50 KVA Capacity min.
Tensile Test Machine: (200 Tons Capacity)	High Pressure Hydraulic Cylinder Type Equipped With Instruments For Recording Tension, Torque Moment, Elongation & Rotation
Temperature Monitoring and Recording Equipment	-
Laboratory Terminations:	Conventional High Voltage AC Sealing Ends Rated: 500 kV - Loading Cycle & Polarity Reversals 230 kV - Impulse Tests 400 kV - DC Tests
Low and High Pressure Oil Reservoirs:	
A2/120 Reservoirs (2)	Non-pressurized 120 Liters
P2/25 Reservoirs (18)	Pressurized 25 Liters
Oil Processing Equipment:	
Oil Pumping Plant	1000 kPa (10 bars)
Degassifier	600 Liters per Hour
Oil Draining Vacuum Pumps (2)	-
Oil Filtration Equipment	-
Small Trolleys (80)	-
Ramps (4)	-
Heat Insulation (200 m)	-